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ENERGY SECURITY: INVESTIGATING WIND ENERGY FOR AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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ABSTRACT

Establishing a low carbon energy mix to reduce the acceleration of climate change is key for countries, organizations and industries providing services and producing goods for public consumption. Establishing a new energy source for the purposes of satisfying energy needs is a challenge that has many dimensions. Most endeavours to establish alternative energy sources in developing countries face unique challenges that may render their establishment as a reliable energy source unsuccessful. Wind energy is particularly difficult to harness for airports due to wind turbine technology operations being incompatible with the radar operations of airports. This paper presents the investigation of establishing a suitable wind energy technology including its technical and economic assessment (technoeconomic assessment) to ensure a reliable and feasible transition for airports in South Africa.

KEYWORDS: Technoeconomic assessments, renewable energy, alternative energy, feasibility of renewable energy, wind energy, airports and wind turbines, vertical axis wind turbines

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Original Article

INTRODUCTION

Wind energy is a very old form of harvesting energy and has been around for centuries in the form of windmills. The progress of science and engineering has led to more efficient, durable and reliable designs for various wind speeds. Due to airport operations relying heavily on radar communications for the successful landing and take-off of aircraft, it is not suitable to have horizontal axis wind turbines made of metal, generating energy through spinning of their turbine blades, because this will deflect and corrupt radar communicate signals. It is for this reason that the selection of the type of wind turbine, design, height, maximum speed and positioning at an airport is critical. Wind technologies allow for output to be scalable at the design stage, however, its output varies throughout the day because wind is variable, and this requires the integration of its output to be carefully designed and intermittencies catered for to ensure that there is continuous energy supply for airport operations as intended. Although wind energy is a renewable resource, the wind speeds vary across the planet, making some areas more eligible than others to install wind turbines for wind energy harvesting. To maximise investment, it is logical to construct wind farms where wind speeds are favourable.

Airports Company South Africa is committed to significantly reduce its carbon emissions in the next 10 to 15 years across the nine airports it owns and operates in South Africa so has embarked on investigating alternative energy sources. Wind power is one of the energy sources being investigated to serve their airports' varying energy load, as an accompaniment to the airports' main energy sources and as a carbon offsetting plant. This pre-feasibility and technology assessment study, which is in second stage of the Front-End Loading or FEL 2 Technoeconomic assessment, is typically done after a strategy is complete and a conceptual study (FEL 1) has been conducted to

identify the technologies that will realize the strategy.

This study covers the technology description, identification of the technology type, typical components constituting the technology, the dynamics around their co-existence with the airport environment, the assessment of technology maturity, the cost-benefit analysis that looks at the investment required, the energy derived and the feasibility indicators of the investment, together with a sensitivity analysis. The technoeconomic study also investigates the technology risk assessment and presents design mitigations. The airport integration strategy is presented as well as the proposed operational philosophy.

Airports Company South Africa is South Africa's airport authority, owning and operating nine airports in South Africa, namely, O R Tambo International Airport (Kempton Park, Gauteng), Cape Town International Airport (Western Cape), King Shaka International Airport (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

The key parameters for vertical axis wind turbines (VAWT) to produce electricity at an airport for airports owned and operated by Airports Company South Africa are as follows [1]:

- A minimum operational speed of about 2 m/s (cut-in speed) most of the year (80 % of the hours in a year).
- A wind speed of 45 m/s for at least 30 % of the year for wind turbines to reach their maximum rated capacity, however, wind speeds should not exceed 50 m/s for more than 50 % of the year.
- Available space for a wind turbine installation that experiences the wind speeds described above unhindered by structures, yet not in the flight path and preferably not within 500 metres of buildings or structures that have a daily foot count of people or communications equipment.

The key parameters for the VAWT Technology to be adopted at airports owned and operated by Airports Company South Africa are:

- Must have the potential to reduce the airport's carbon footprint.
- Must make financial sense to the business.
- Must meet all South African Civil Aviation requirements.
- Operational and Technical risks should be acceptable.

1. Description of the Technology

Wind is created from the difference in temperatures of atmospheric air caused by uneven heating of the earth's atmosphere and surface. This imbalance of warm and cool air creates wind (Figure 1).

Harnessing wind energy is through the conversion of the force of moving air molecules against, for example, an object that can rotate (kinetic energy) which is typically then converted to shaft speed within an electrical generator via a gearbox and this creates electricity for use on site.

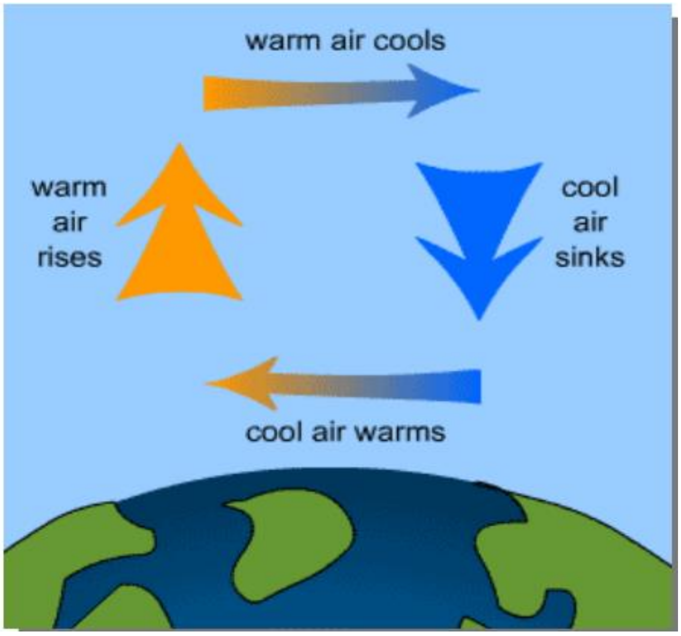


Figure 1: How Global Winds are formed [2]

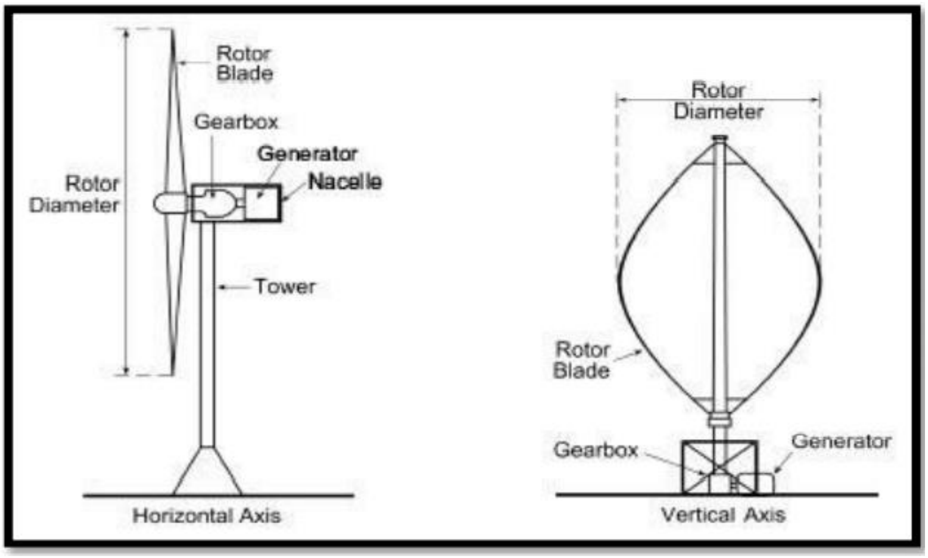


Figure 2: Horizontal and Vertical Axis Wind Turbines Configuration [3]

The preferred technology for harnessing wind energy at airports is VAWT due to their rotational axis not being on the same plane as the aircraft propeller or jet engine turbines and therefore interruptions and confused radar signals are minimized and can be mitigated. Figure 2 shows the differences in configuration of vertical axis and horizontal axis wind turbines (HAWT). This configuration is also preferable for safety reasons. When the generator of wind turbines catch fire, due to the accessibility, it is quite difficult to address. The VAWT has its generator at the base of the wind turbine, located on the ground.

Wind Turbines will typically be connected in series and their direct current (DC) output will be converted using an inverter and this will be sent to a point of connection point where, depending on the design, the grid integration requirements such as voltage step up may be achieved prior to connection to the grid (for grid-tied) systems. Where a site

has multiple systems, the current may feed into a point of common coupling for take-off to multiple users. Figure 3 shows a typical connection.

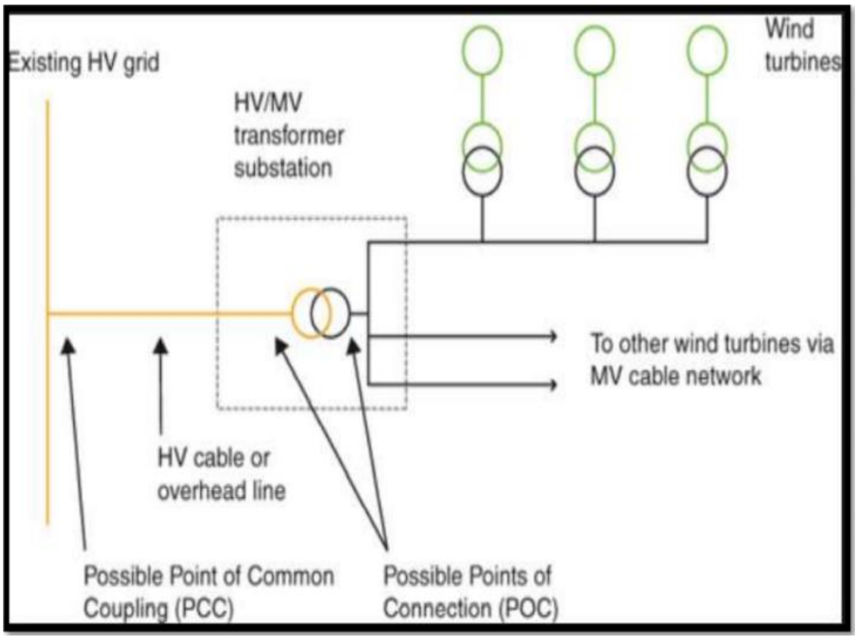


Figure 3: Wind Energy typical Single Line Diagram[4]

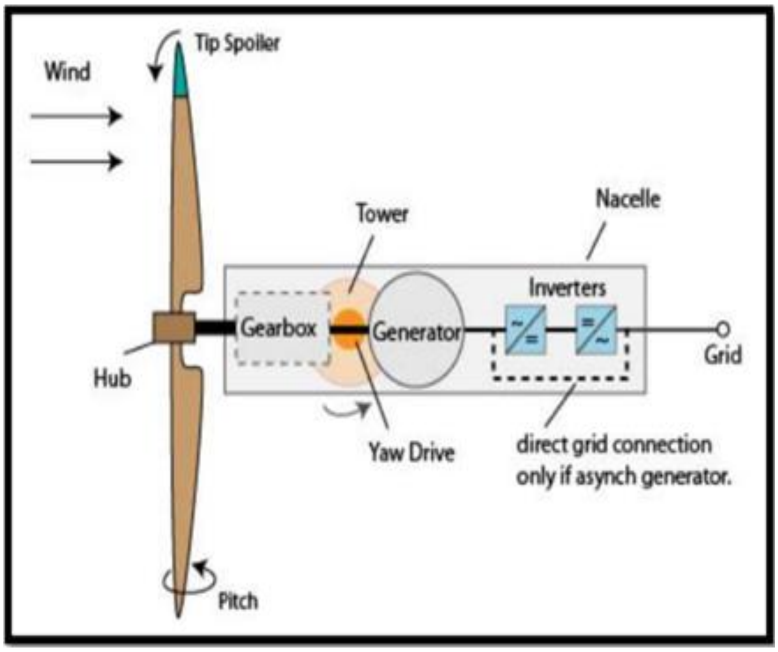


Figure 4: Typical components of a Wind Turbine [5]

The components of a typical wind turbine are seen in Fig 4. In principle, the turbine blades turn the shaft that it is mounted on and this shaft rotation is gear ratioed in the gearbox to deliver a consistent shaft rotation in a generator. The generator output is in direct current (DC) and then needs to be converted using inverters to alternating current (AC).

Typically, in a wind farm arrangement, many wind turbine generators are connected in strings (series or parallel

depending on the electrical design of the voltages and currents). The output of each string will then be connected to a point of connection (POC) where, typically, voltage will be stepped up to match that of the grid in a grid-tied connection. This will then be joined to a point of common coupling (PCC). The gearbox is the maintenance intensive part of this set up and thus an alternative which is less maintenance intensive, with fewer moving parts should be considered to lower operational costs. Flywheel storage together with power electronics is ideal for "ironing out" shaft rotation intermittencies.

The use of an induction motor should be considered; this system should work like an electric car in regenerative braking mode. This arrangement uses kinetic energy to drive the stator of the induction motor which in turn induces a current on a rotor which uses power electronics to control the rotor and RMF (rotating magnetic field) speed such that the rotor speed is greater than the RMF speed, making the induction motor a generator.

The proposed set up is depicted in Figure 5. The fly wheel storage irons out intermittencies in the kinetic energy of the wind turbine and sends the rotation to the stator of an induction motor, inducing a current in the rotor with the power electronics ensuring the rotor speed is greater than the RMF speed. The current produced is DC, which can be converted to AC using an inverter for use by the facility.

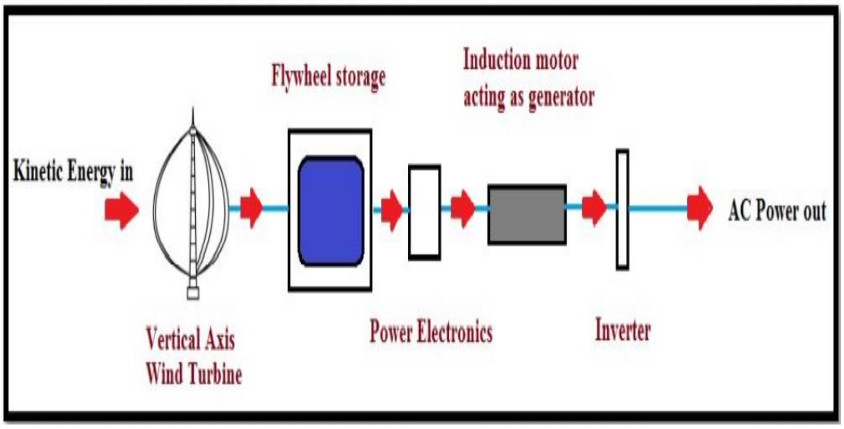


Figure 5: Proposed Electricity Generation by Harnessing Wind Energy

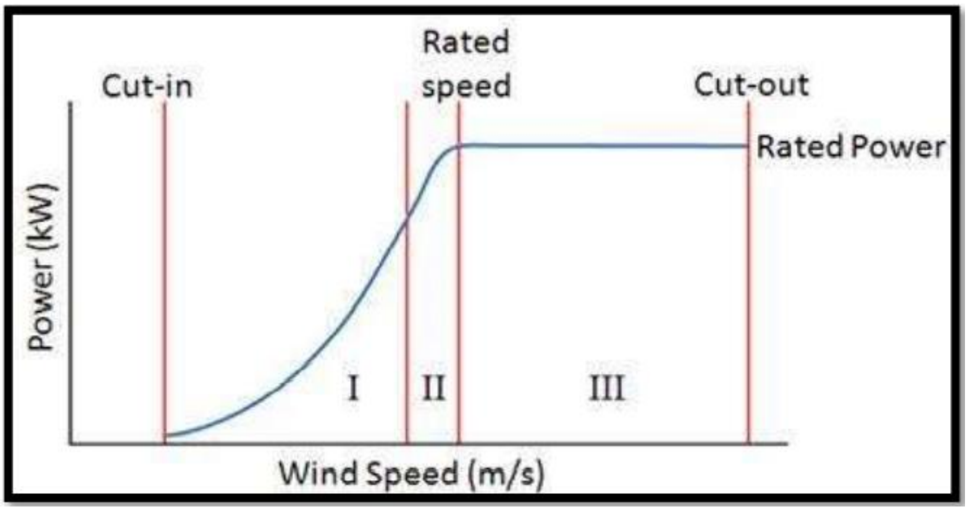


Figure 6: Ideal Wind Turbine Power Curve [6]

Wind speed varies throughout the day based on the fluctuations experienced as depicted in Figure 1. The output power of the wind turbine is limited to the motor capacity as per the rated power of the generator. The minimum wind speed required to overcome friction and turn the turbine blades and generate power is the "cut-in speed", and the "cut out speed" is the speed at which the turbine blades are brought to rest to avoid damage from high winds. The rated speed is the wind speed at which the turbine can generate electricity at its maximum, or rated capacity. These various parameters are depicted in Figure 6.

The equation governing the power harnessed from wind energy using wind turbines can be seen in Equation 1.

$Maximum\ Wind\ Power = \frac{1}{2} C_p \rho A V^3$ ……………………………………………………….Equation 1

Where:

C_p is the coefficient of performance and is governed by the Betz limit which is 0,59

ρ is the density of the air

A is the swept area

V is the wind velocity

Factors such as the generator efficiency and the efficiency of the power converter and other devices (flywheel or gearbox) depending on the configuration need to be taken into consideration when looking for the actual power production.

Wind turbines can be designed to use aeronautical lift or drag. The key differences can be seen in Figure 7.

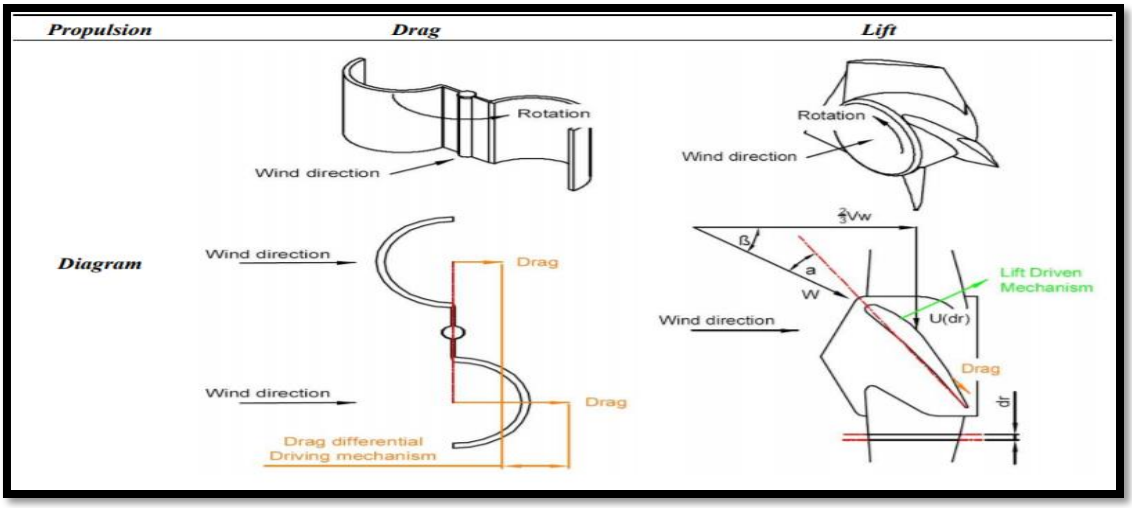


Figure 7: Two Mechanisms of Propulsion Compared [7]

The various efficiencies of the drag and lift designs can be seen in Fig 8. The reason for the choice of VAWT over the HAWT in an airport environment is due to the design of the VAWT being less intrusive on the communication (radar) signals. Moving metal can distort radar signals, thus moving turbine blades are not ideal in an airport environment. Radar may misinterpret signals due to the possible confusion of the moving clutter caused by turbine blades which they are unable to filter out (Figure 9). The signals from fixed clutter ("noise") can be filtered out to detect the position of an aircraft (which is in motion and is the purpose of radar at an airport); however, when the radar signals deflected off turbine

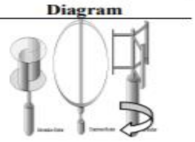
blades are received, they can be seen as and mistaken for "moving aircraft" causing "noise". The "noise" generated by the wind turbine blades also have the capacity to impede the "listening ability" of radar receiving stations for approaching aircraft. This is also true for the audible noise generated by the wind turbines turning that is disruptive to human biological systems. It is therefore recommended that these installations are at least 300metres away from human settlements (Figure 10).

Choosing VAWT over HAWT wind turbines for an airport environment does not necessarily eliminate this risk of signal distortion but plays a role in reducing the significance and even the possibility of this happening depending on the material choice for the turbine blades.

The design considered for implementation at airports can be seen in number 6 on Figure 8. The Darrieus Rotor with a 40% efficiency, which when compared to the traditional efficient three blade HAWT in number 7, is 10% less efficient.

There is a four-storey high (about 8m height) installation of three VAWT of the Darrieus type installed at Hotel Verde within a kilometre radius from the Cape Town International Airport central terminal building. The installation is owned and operated by the hotel. Taking learnings from that installation, the installation of the turbines should preferably not be within the communications path of aircraft movements, landings or take-offs and the control tower or their communications systems.

The height of the VAWT is usually based on the desired wind speed most of the time, however, for airport installations there is an added restraint of the "obstacle avoidance" requirement within the aerodrome from the International Civil Aviation Authority (ICAO) which limits the height of any structure. In the case that the VAWT is outside of the aerodrome, the height regulations will be governed by CAA (Civil Aviation Authority) requirements.

Ref No.	Design	Orientation	Use	Propulsion	* Peak Efficiency	Diagram
1	Savonius rotor	VAWT	Historic Persian windmill to modern day ventilation	Drag	16%	
2	Cup	VAWT	Modern day cup anemometer	Drag	8%	
3	American farm windmill	HAWT	18th century to present day, farm use for Pumping water, grinding wheat, generating electricity	Lift	31%	
4	Dutch Windmill	HAWT	16th Century, used for grinding wheat.	Lift	27%	
5	Darrieus Rotor (egg beater)	VAWT	20th century, electricity generation	Lift	40%	
6	Modern Wind Turbine	HAWT	20th century, electricity generation	Lift	Blade Qty / efficiency 1 / 43% 2 / 47% 3 / 50%	

* Peak efficiency is dependent upon design, values quoted are maximum efficiencies of designs in operation to date [1].

Figure 8: Modern and historical rotor designs [7]

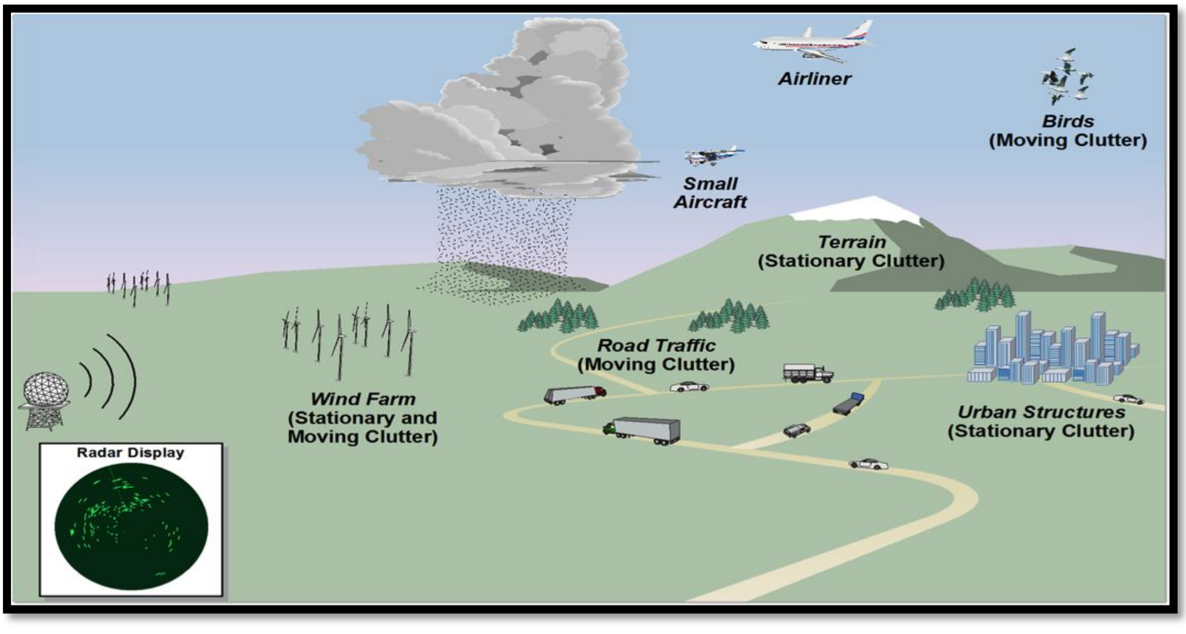


Figure 9: Radar and Wind Turbines [8]

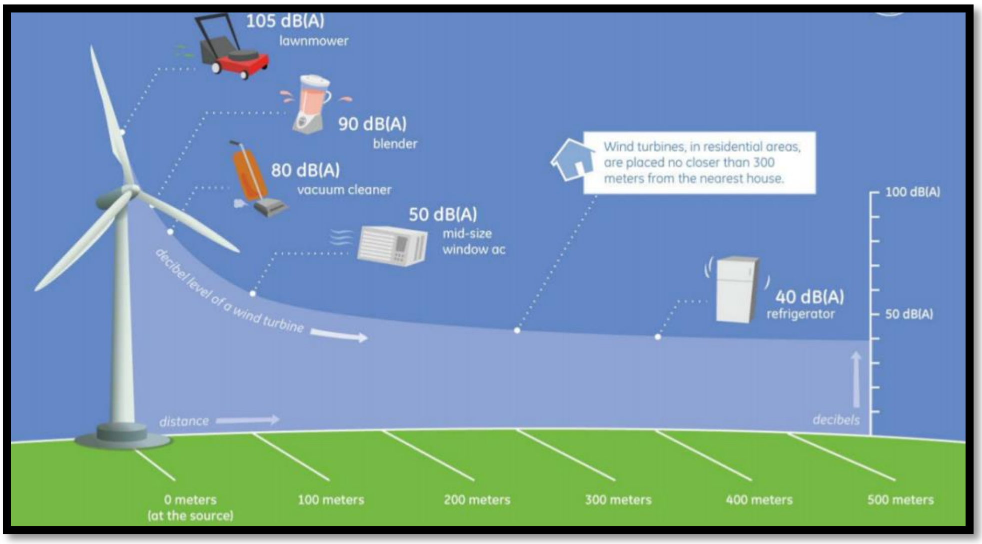


Figure 10: Audible Noise and Human Settlements [9]

2. Assessment of Technology Maturity

Wind turbines have been in existence since the first century AD, with their evolution captured in Figure 11. The installed capacities of wind farms around the world by country can be seen in Figure 12. The USA and Germany are leading in the capacity of wind power generation installations with installed capacities increasing by 5 times over the last two decades. Figure 13 shows that harnessing wind energy is among the second most popular choices when it comes to the uptake of renewable energy globally, even more popular than solar energy installations.

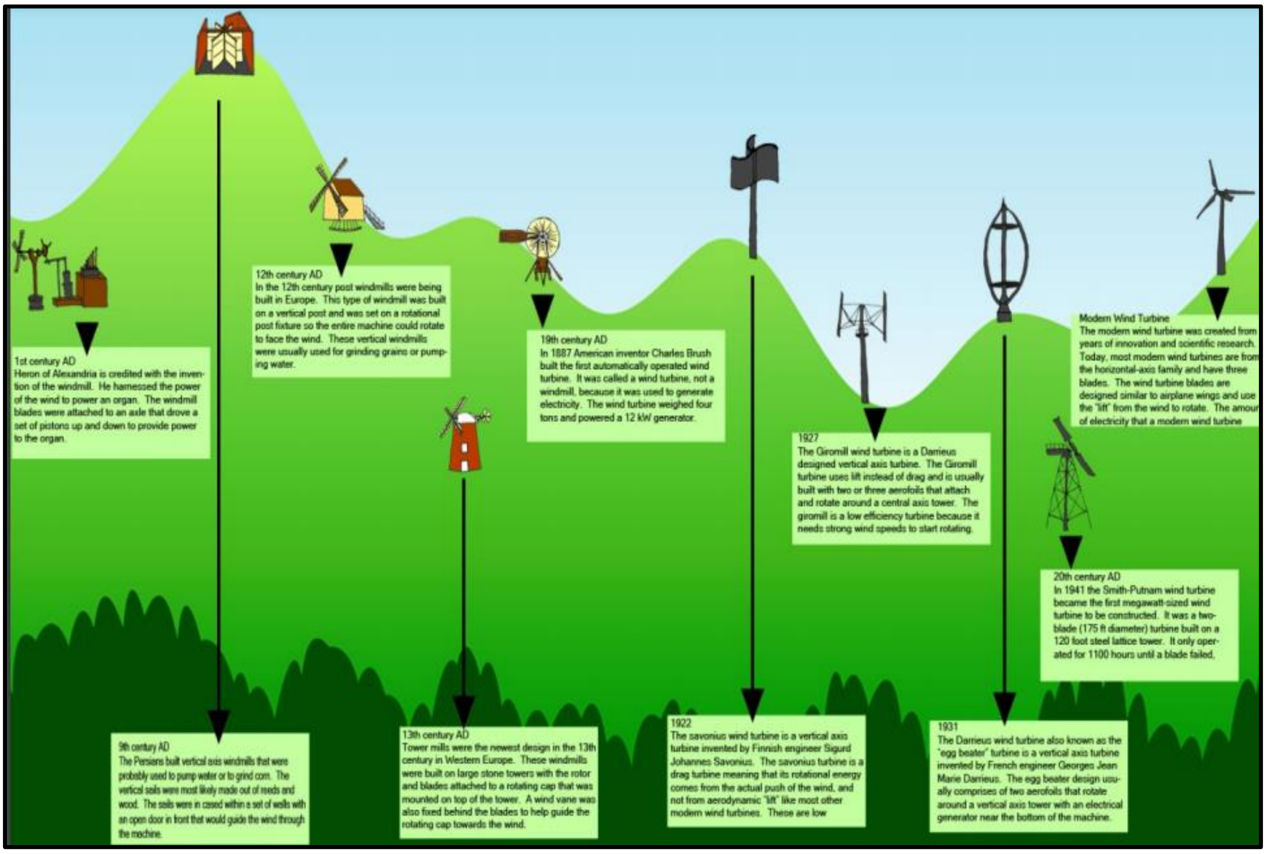
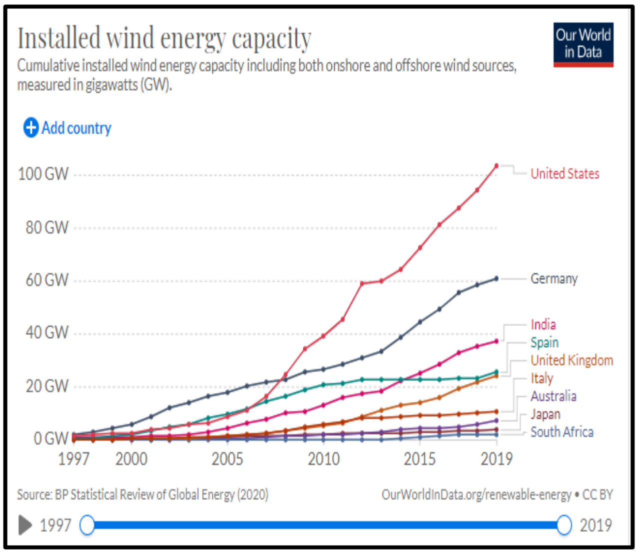


Figure 11: Evolution of Wind Turbines [2]



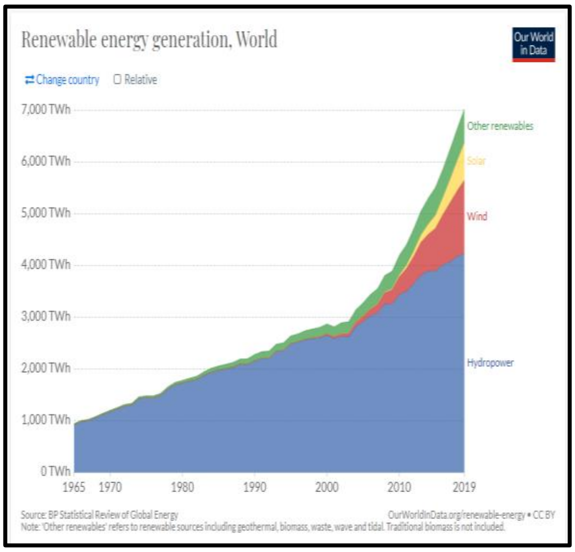


Figure 12: Installed Wind Energy Capacities around the world [10]

Figure 13: Wind Energy use in relation to other renewables in the energy space [111

"The origins and use of flywheel technology for mechanical energy storage began several 100 years ago and was developed throughout the Industrial Revolution. One of the first 'modern' dissertations on the theoretical stress limitations of rotational disks (isotropic only) is the seminal work by Dr. A. Stodola whose first translation to English was made in 1917. The next big milestones were during the 1960s and 1970s when NASA sponsored programs proposed energy storage

flywheels as possible primary sources for space missions. However, it was not until the 1980s when microelectronics, magnetic bearing systems and high-power density motor-generators became enabling technologies. The next decade proved that a mechanical battery could surpass chemical batteries for many applications." [12]

South Africa has several wind farm installations From Figure 12 it can be seen that the installations began showing increase in capacity from 2015. A wind farm using the Darrieus turbine in South Africa is located at Hotel Verde on Cape Town International Airport's site (Figure 14 and Figure 15).

Figure 14: Darrieus VAWT installed at Hotel Verde, 1 km away from CTIA in South Africa [13]

Figure 15: Hotel Verde Vertical Axis Wind Turbines [14]

Harvesting wind energy using wind turbines is not a new concept, and neither is the technology, but the suggested configuration (VAWT) presented in Figure 5 is novel. The probability that the configuration will work is highly likely from a technology perspective as the technology works well independently and is available on the commercial market. It is recommended that this configuration be trialled in relation to airport integration.

3. Cost-benefit analysis

Due to this techno economic assessment being a desktop exercise meant to provide an indication of the economics and suitability of wind energy for airports at pre-feasibility (FEL2 or Front-End Loading Stage 2); the airports targeted for harvesting wind energy have been determined from the trend of wind farms installed by other organizations and government driven projects in South Africa. From Figure 16it is evident that there is a clustering of wind farm installations located on South Africa's west and south coasts. The establishment of wind farms in these areas prove that the technology will harvest wind energy in these regions.

(a) Feasibility Study

The targeted airports for implementation are based on where wind farm installations are currently located in South Africa. The installations of wind power are concentrated in the Eastern Cape and Western Cape of South Africa, which makes four of ACSA's airports eligible for successfully harnessing of wind power, namely East London, George, Port Elizabeth and Cape Town airports.

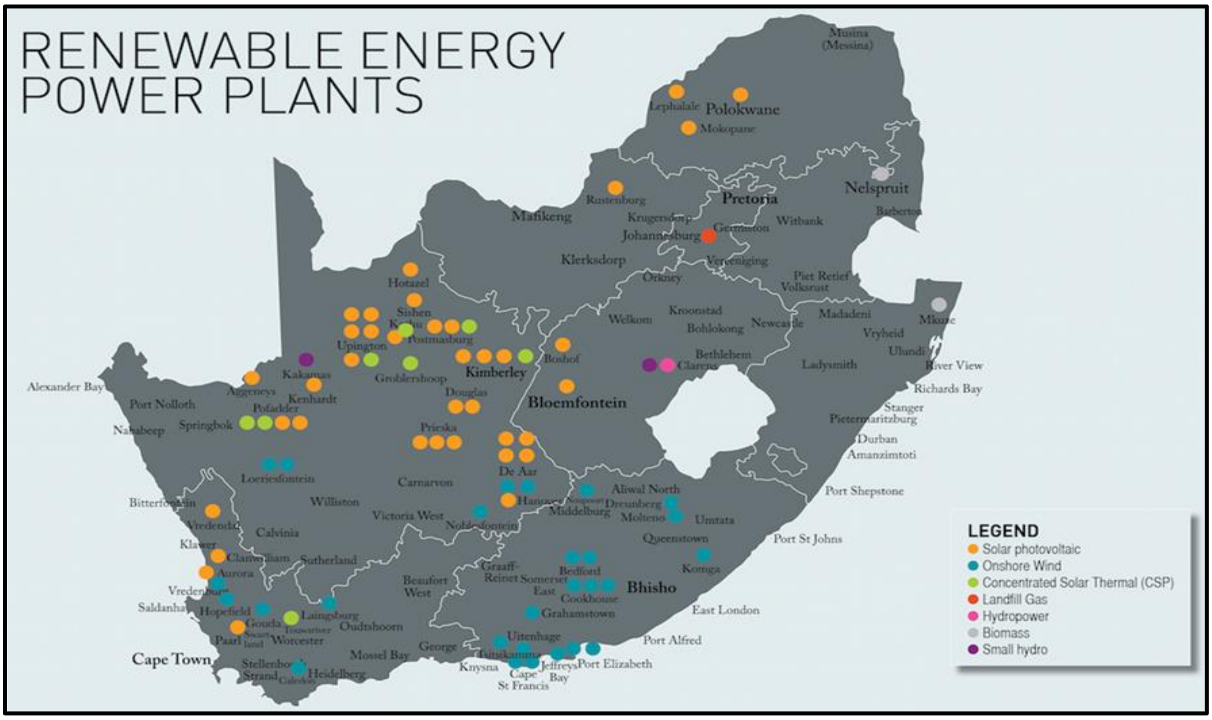


Figure 16: Renewable Energy Power Plants in South Africa showing concentration of Wind Power Plant Installations [15]

Due to wind turbine technology being generally unsuitable for an airport environment, it was decided that large wind power farm installations would not be the intention for airports, whether to serve as an electrical base load or to serve the varying electrical load requirements as performed in the energy mix exercise completed for Airports Company South Africa.

Wind farms could, however, be adopted in small numbers as a supplement to the airport's low carbon energy mix to make up for the shortfall in carbon footprint offset required towards carbon neutrality for the airport site. Land availability co-incidentally is an issue with airports in that open land areas are usually reserved for future airport development. The scale of the wind power plants in each of the four regions were based on the available land area that met the following criteria:

- Outside of a 1km radius from radar and communications
- Outside the aerodrome
- Not reserved for commercial or future airport development
- Outside of the flight path of landing and taking off aircraft and their communications with radar stations

The areas identified at each of the four airports were as follows:

- Cape Town International Airport (CTIA) – 20 000 m^2
- Port Elizabeth International Airport (PEIA) – 22 000 m^2
- East London Airport (EL) – 10 000 m^2

- George Airport (GG) – 94 681 m^2

Due to George Airport having a solar photovoltaic farm that generates electricity onsite for use at the airport, the full wind power generation capacity of the 94 681 m^2 of land will not be required, with only 30% required to make the shortfall of electricity requirements not met by the existing solar photovoltaic farm.

In order to proceed with the pre-feasibility calculations to get an indication of a business case, it was necessary to choose a suitable commercially available VAWT to get pricing data for the economic models. Table 1 shows the specifications of the VAWT that was chosen. The costing data and economic model presented here was performed in 2018 and the report was submitted in March 2019.

Ft-Q4 VAWT [1] is designed with maglev and Darrieus technology. It is made of lightweight aluminium alloy. Owing to the advanced maglev technology and the power of super magnets, VAWT starts with low wind speed and works stably. It is not affected by the direction of the wind, which is useful in areas where the wind changes direction frequently and quickly. VAWT out performs HAWT in areas where a tall tower is not feasible, like in airport installations where the height is restricted by ICAO regulations. The recommended spacing for wind farms and that which is used in this business case is 4 rotor diameters, rotor diameter taken to be 2.5m as per the specifications in Table 1. The height of the VAWT is taken to be restricted at 10 m which is the height of a typical street light pole.

The cost of the VAWT is US$1300 each, using a conversion factor of US$1 is ZAR14.33 (2018), the capital required per VAWT of 1kW rated capacity was estimated using two components, i.e.:

- Cost of VAWT: US$ 1300 x ZAR 14.33 = ZAR 18 629
- Cost of installation: 0.2 x cost of VAWT = ZAR 3 725.8
- Cost per kW = ZAR22 355

The cost of annual maintenance is assumed to be 5% of the total capital expenditure required for the installation. Table 2 shows the cost and installation capacities of the wind power generation, based on the above costs.

Table 1: Specifications of VAWT used in the Economic calculations[16]

Rated Power	1kW
Max Power	1.2kW
Start Wind Speed	2m/s
Rated Wind speed	13m/s
Working Wind Speed	3 m/s to 45m/s
Safety Wind speed	50m/s
Blades Length	2.3m
Blades Rotor Diameter	2.5m
Blades Material	Casting aluminium alloy
Turbine Weight	180kg
Generator Type	maglev
Rated speed	300rpm
Option Voltage	24V/48V/96V
Protection Method	Electromagnetic
Protection Grade	IP54
Working Temperature	From -40℃ to 80℃
Lifetime	20 years

Table 2: Summary of Wind Power Generation Capacities and costs for the Selected Airports

	land available (m^2)	**wind turbines installation (1kW turbines)**	**power generated (kWhs)**
CTIA	20000	255	781 146
CAPEX		ZAR 5 700 474	
Annual maintenance cost		ZAR 285 024	
	land available (m^2)	**wind turbines installation (1kW turbines)**	**power generated (kWhs)**
PEIA	22000	280	858 480
CAPEX		ZAR 6 265 039,49	
Annual maintenance cost		ZAR 313 251,97	
	land available (m^2)	**wind turbines installation (1kW turbines)**	**power generated (kWhs)**
EL	10000	127	390 573
CAPEX		ZAR 2 847 745,22	
Annual maintenance cost		ZAR 142 387,26	
	land available (m^2)	**wind turbines installation (1kW turbines)**	**power generated (kWhs)**
GG	94681	362	1 109 396
CAPEX		ZAR 8 088 821,0	
Annual maintenance cost		ZAR 808 882,10	

Airports Company South Africa has an economic modelling department that creates economic models in Excel spreadsheets. The inputs used in the economic model and the financial outputs for the Cape Town, Port Elizabeth, East London and George airports can be seen in Table 3, Table 4, Table 5 and Table 6. A capacity factor of 35% is used for the kWh production from the wind farm installation.

The economic model yields the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index. The IRR is compared to ACSA's 11.5% weighted average cost of capital (WACC) rate(2018) to determine economic feasibility. When the NPV is zero or positive it is an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2), the IRR is the return (i in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index or PI (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^{T} \frac{R_t}{(1+i)^t} \qquad \text{Equation 2}$$

Where:

R_t = net cash inflows – outflows during a single period t

i= discount rate or return that could be earned

t = number of time periods

$PI = \frac{PV\ of\ future\ cash\ flows}{Initial\ Investment}$ ……………………………………………………………………Equation 3

In summary:

- Cape Town International Airport – For a 255kW VAWT plant, the NPV is ZAR3.74m (positive) and the IRR is 22.6% which exceeds the ACSA WACC rate of 11.5%.This shows that the installation is feasible.
- Port Elizabeth International Airport – For a 280kW VAWT plant, the NPV is ZAR3,15m (positive) and the IRR is 21.3% which exceeds the ACSA WACC rate of 11.5%.This shows that the installation is feasible.
- East London Airport – For a 127kW VAWT plant, the NPV is -ZAR0,58m (negative) and the IRR is 6,4% which is below the ACSA WACC rate of 11,5%.This shows that the installation is not feasible.
- George Airport – For a 362kW VAWT plant, the NPV is -ZAR1m (negative) and IRR is 8.6 % which is below the ACSA WACC rate of 11.5%.This shows that the installation is not feasible.

Table 3: Summarized Economic Analysis – Cape Town International Airport

Inputs		Output	
kW wind rated capacity	255	End of Job cost	ZAR 7.31m
Capital cost @ 2018	ZAR5 700 474	Net Present Value	ZAR 3.74m
Electricity saving at beneficial operation	783 972kWh/annum	Internal Rate of Return	22.6%
Electricity cost (2018)	ZAR1.47/kWh	Nominal payback period	5 years
Beneficial operation	2024	Profitability index	1.88
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 285 024/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.23		

Table 4: Summarized Economic Analysis – Port Elizabeth International Airport

Inputs		Output	
kW wind rated capacity	280	End of job cost	ZAR 8.87m
Capital cost @ 2018	ZAR 6 259 344	Net present value	ZAR 3.15m
Electricity saving at beneficial operation	858 480kWh/annum	Internal rate of return	21.3%
Electricity cost (2018)	ZAR 1.29/kWh	Nominal payback period	5 years
Beneficial operation	2026	Profitability index	1.76
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 312 967/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.42		

Table 5: Summarized Economic Analysis – East London Airport

Inputs		Output	
kW wind rated capacity	127	End of job cost	ZAR 4.02m
Capital cost @ 2018	ZAR 2 839 060	Net present value	-ZAR 0.58m
Electricity saving at beneficial operation	389 382kWh/annum	Internal rate of return	6.4%
Electricity cost (2018)	ZAR 0.60/kWh	Nominal payback period	10 years
Beneficial operation	2026	Profitability index	0.69
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 141 953/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.42		

Table 6: Summarized economic analysis – George Airport

Inputs		Output	
kW wind rated capacity	362	End of job cost	ZAR 11.46m
Capital cost @ 2018	ZAR 8 092 438	Net present value	-ZAR 1m
Electricity saving at beneficial operation	1 109 892 kWh/annum	Internal rate of return	8.6%
Electricity cost (2018)	ZAR 0.60/kWh	Nominal payback period	9 years
Beneficial operation	2026	Profitability index	0.81
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	15 years		
Degradation	0.5% per annum		
Operational and maintenance cost	ZAR 404 622/annum (2018 terms)		
Eskom tariff escalation factor	5.1% per annum		
CAPEX escalation factor	1.42		

This pre-feasibility study (FEL2) conducted for the four selected airports show that two wind farm installations are feasible (Cape Town International Airport and Port Elizabeth International Airport) and two wind farm installation are not feasible (East London Airport and George Airport). To determine the factors that this pre-feasibility study is most sensitive to, a sensitivity analysis was conducted.

(b) Sensitivity Analysis

For the sensitivity analysis, the three factors that play a role in the determination of the profitability of the investment were varied equally to see the significance of the impact each parameter had on profitability relative to each other. The base cases used for the airports that had feasible economic results are described in Table 3 and Table 4.

The profitability of the investment relies on the capital cost of the installation, the cost of electricity from Eskom and the operational cost of the VAWT plants. The effect that these three factors have on the NPV of the installations can be seen in Figure 17 and Figure 18.

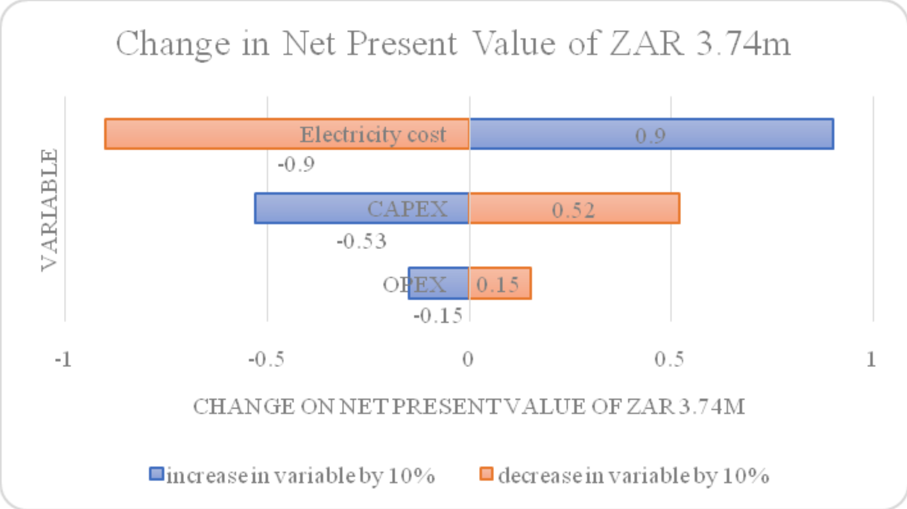


Figure 17: Sensitivity analysis of the CTIA Wind Farm Installation

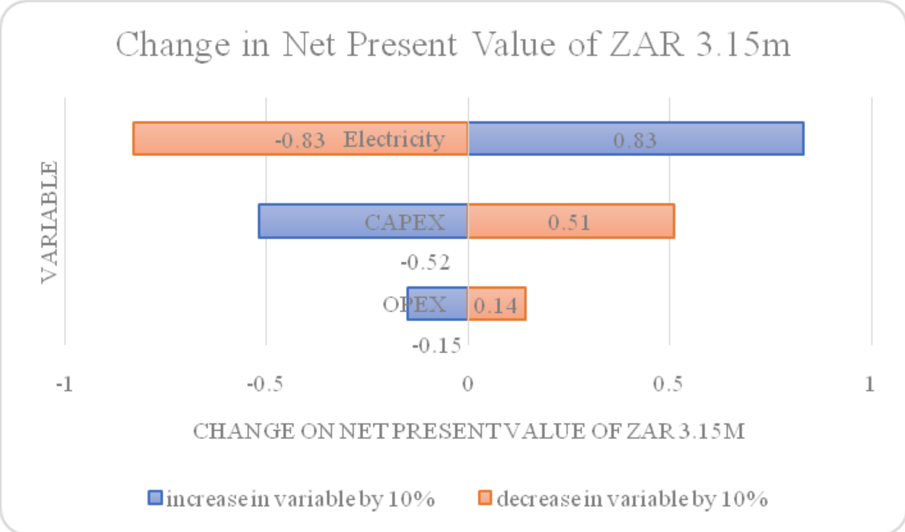


Figure 18: Sensitivity analysis of the PEIA Wind Farm Installation

A 10% increase or a 10 % decrease in the CAPEX, OPEX, electricity cost and water cost show that the electricity cost is the most significant factor and the operational cost the least significant factor in the feasibility of the wind farm investments for CTIA and PEIA. A 10% increase in the electricity cost results in an increase in the NPV of ZAR 0.9m for CTIA and ZAR 0.83m for PEIA, however a 10% decrease in the electricity cost shows a decrease in NPV of ZAR 0.9m for CTIA and ZAR 0.83m for PEIA. The effect of a10% change in CAPEX has just over half of the effect that the 10 % change in electricity cost has on the NPV of ZAR 3.15m. The effect that a 10 % change in OPEX has on the NPV of ZAR 3.15m is the least significant in comparison to the effect of the changes in CAPEX and electricity cost of same magnitude on the NPV of ZAR 3.15m.These results tell us that we should monitor the electricity tariffs of the airports closely as a change will affect the feasibility of the investment. The results also show that the feasibility is sound in that even a 10 % change in the electricity, capital expenditure required, or operational expenditure required will not make the investment into the wind farms unfeasible.

4. Technology Risk Assessment

The technologies that make up the wind farm installation can be seen in Figure 5. The Darrieus VAWT has been around for about eight decades and the related systems such as the flywheel and induction motor have evolved over a much longer period. The technology risk assessment in this context is provided in Table 7.

Table 7: Technology Risk Assessment

Risk	Description	Possible Mitigation
Insufficient wind for upkeep of flywheel output	Wind is intermittent throughout the day and night; however, a smooth power output is required for use at airports.	1. Using flywheel storage instead of a gearbox to ensure a smoothing out of generation intermittencies will require an intelligent control system (power electronics) coupled with an induction generator. 2. An intelligent control system should be employed to ensure that the flywheel is able to respond to the intermittencies of the wind turbine and still give a smooth output without frequent shutdowns within the day. 3. The flywheel's charge and discharge periods should also be variable to enable optimum control for a smooth output to the generator.
Single point of failure	This is failure at a single point at which without it the entire plant will not be able to operate. This will include failure at the point of connection.	1. Design flexibility should be introduced so that should a failure occur at the point of connection, it can be isolated, bypassed and another point of connection with spare capacity is able to carry the load while the failed point of connection is being restored. 2. Back-up energy storage or generation systems connected in parallel with the point of connection designed to carry the full load should be part of the wind farm design and smart electricity grid configuration. 3. Active monitoring and early detection of failure should be incorporated. A fail-safe mode or default mode should be programmed/hard-wired into the system in case of loss of the control system or smart grid.
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	The wind plant's output is dependent on the wind speed of the prevailing winds experienced on site and is, thus, by nature, intermittent. The wind plant will then never be a stand-alone power generation source but will be coupled with another generation source/s which will make up for its intermittency. Grid-tied design is suitable for a site that just has Eskom power as well as a site that has a smart system including power control for a site that has multiple power generation sources. The smart electrical grid design should ideally coordinate all power sources.
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased in capacity to suit operations, site demand and maintenance regimes to maintain cost effectiveness.	The ability to ground and release certain turbines and strings to "bring in loads" and "turn down loads" should be part of control system designs.

5. Airports' Integration Strategy

Due to wind farms being novel to the ACSA airport environment and field of experience, collaboration and investigations as well as a pilot installation is required to ensure that the technology's installation will not have adverse effects on airport

operations, specifically, radar communications. It is therefore required that the Air Traffic Navigational Services (ATNS) and the South African Civil Aviation Authority (SACAA) be consulted and their respective requirements be adhered to in the course of wind farm installation.

ACSA needs to be assured that their investment will not result in undesirable, unavoidable, costly impacts on the business. For this reason, the roll-out of the installation of wind farms need to take place in phases to prove that the site selected and the wind turbines' height and 'sight' in respect of the radar communications are acceptable to airport operations. Figure 19 shows the proposed roll-out plan to ensure that wind farm installations are successful in their coexistence with airport environments. The four phases of the proposed rollout identify eligible sites for the wind farm installation; the installation of about 10 wind turbines each at both Port Elizabeth International Airport and Cape Town International Airport, not connected to the airport grid allowing for flexibility so that they can be moved about should the site selected not be suitable to airport radar communications. The observation and recording of radar communication interactions in all operational conditions in the presence of the wind farm will be undertaken.

The roll-out will provide information related to:

- Site selection of the wind farm installation,
- Height of the wind turbines,
- The unimpacted radar communications "sight" of the wind turbines, and
- Effect of the multiplication of the number of wind turbines that is required for the full wind farm installation.

The next phase of the installation is the full wind farm which should be established based on the assurance received from the previous phase. However, should the first phase of installation not provide assurance on any of the points given, alternative sites should be considered. If the alternative eligible sites identified at the respective airport fail to provide the assurance, the wind turbines purchased should be transferred to another airport in the group where the roll-out plan was successfully completed, to constitute the wind farm there. Should transferring to another airport not be an option, an offsite plant used for "carbon footprint offsetting" should be considered.

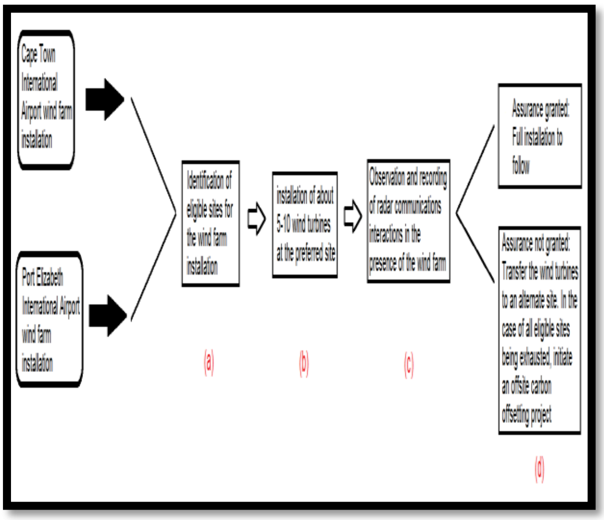


Figure 19: Phases of integration of Wind Energy at ACSA

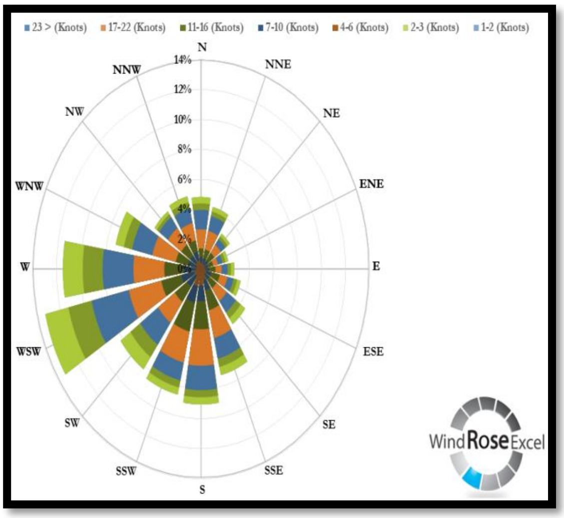


Figure 20: Wind Rose Diagram [17]

The following sections contain information for the execution of the phases which will follow the FEL2 techno economic study, as laid out in Figure 19.

(a) Identification of eligible sites for wind farm installation

The study should consider the requirements of the SACAA, ICAO and ATNS as well as OEM requirements of radar equipment to identify eligible sites, taking care to select those sites that are favourable to higher wind speeds for the majority of the time as seen in the wind rose diagram in Figure 20. Outputs of the study for the eligible sites must provide wind rose diagrams, and the height and maximum number of wind turbines that can be accommodated within the site. The measuring station should consider the following:

- The height allowable by the SACAA, ICAO and ATNS.
- The distance away from the radar equipment such that the radar is not affected by wind turbines.

Figure 21 and Figure 22 show the eligible sites identified for CTIA and PEIA respectively. These eligible sites identified by ACSA were then discussed with the CAA and ATNS. Table 8 and Table 9 show the longitude and latitude of the eligible points for each airport. From each eligible point, a 20 000 m^2land area radiating around it (about 80 m radius)is the land area demarcated for the wind farm. Only one land plot of 20 000 m^2 is required per airport for the wind farm.

Figure 21: Eligible sites identified for wind farm installations at CTIA

Figure 22: Eligible sites identified for wind farm installations at PEIA

Table 8: Longitudes and latitudes of the eligible sites for CTIA Wind Farm Installation

Eligible sites		Degrees	Minutes	Seconds	Latitude/ Longitude
POINT 1	18,6226116	18	37	21	E
	33,9543497	33	57	16	S
POINT 2	18,5936476	18	36	37	E
	33,9638453	33	58	50	S
POINT 3	18,5939816	18	36	38	E
	33,9677581	33	58	4	S
POINT 4	18,5943156	18	36	40	E

	33,9700008	33	58	12	S
POINT 5	18,5912618	18	35	29	E
	33,9710983	33	58	16	S
POINT 6	18,5925024	18	36	33	E
	33,9724343	33	58	21	S
POINT 7	18,5951268	18	36	42	E
	33,9716709	33	58	18	S
POINT 8	18,5990197	18	36	56	E
	33,9806927	33	59	50	S

Table 9: Longitudes and latitudes of the eligible sites for PEIA wind Farm Installation

Eligible sites		**Degrees**	**Minutes**	**Seconds**	**Latitude/ Longitude**
POINT 1	25,6095421	25	37	34	E
	33,9933188	33	60	36	S
POINT 2	25,5804351	25	35	50	E
	34,0026072	34	0	9	S
POINT 3	25,5818867	25	35	55	E
	34,0042892	34	0	15	S
POINT 4	25,5838222	25	35	2	E
	34,0009942	34	0	4	S
POINT 5	25,5855734	25	35	8	E
	34,0031832	34	0	11	S
POINT 6	25,6112159	25	37	40	E
	33,982935	33	59	59	S
POINT 7	25,6112159	25	37	40	E
	33,9827382	33	59	58	S
POINT 8	25,61489	25	37	54	E
	33,982104	33	59	56	S
POINT 9	25,6102761	25	37	37	E
	33,9834833	33	59	1	S
POINT 10	25,6068549	25	36	25	E
	33,9836215	33	59	1	S
POINT 11	25,6066937	25	36	24	E
	33,9849232	33	59	6	S

Any wind farm installation has to be granted permission by the SACAA who collaborates with the ATNS for the approval of the wind farm installation based on the height of the installation, and the line of sight of the wind farm to radar communication towers and equipment. To determine the harmonious coexistence of the wind farm with the airport, the ATNS runs a computer simulation that highlights points of concern given input of certain parameters of the wind farm such as the maximum rated speed of the wind turbines blades, axis of rotation, material of construction, height of turbine, number of turbines and their location spacing and spread. This is a costly exercise,so in an effort to reduce the cost of the preliminary work, a meeting was held with ATNS and SACAA to reduce the number of eligible sites to save on cost. The

meeting with SACAA and ATNS in March 2020 yielded 4 points per airport as the most likely to be approved to co-exist with the airports' radar systems. These points are POINTS3, 4, 7 and 8 for CTIA and POINTS 1, 6, 7 and 9 for PEIA. The next step is to choose one most likely location to be run by the simulation based on the available land, i.e. land not reserved for future development.

(b) Pilot installation

The eligible sites investigated in phase (a) should be characterized in order of preference for the wind farm installation. The installation should not necessarily be feeding into the grid, but the wind turbines should be allowed to turn and have the capability of being "grounded" so that they do not turn for wind speeds that are unsafe or disruptive to airport operations.

(c) Observation and recording of radar communications in the presence of mini/pilot wind farm

In this phase, an observation programme should be carried out on the radar operations with the existence of the pilot sized wind farm. Ideally, the recording of radar operations alone should be done first to establish a baseline against which recording of radar communications with the mini/pilot wind farm installation can be compared. The programme should be agreed upon with technical experts at SACAA and ATNS and all interested and affected parties, requiring sign off for procedures and implementation timeline. Risks should also be identified and managed. It is advisable that a full week of observations occur, with particular care exercised in the first few hours when the radar operations must be very carefully monitored to ensure that no undue risks are present. The results of the observations will lead to a decision regarding whether the full installation follows or whether the pilot installation is relocated at the next preferable eligible site until the requirements for full installation have been satisfied or until the eligible sites have been exhausted.

(d) Full installation

If the results from the pilot phase show that there are no interruptions on the radar operations nor unacceptable risks to airport operations, the pilot/mini installation may proceed to a full installation. In the case that all eligible sites have been exhausted and there is no suitable onsite location for the wind farm, alternative options such as investigating the feasibility of an off-site installation that will either benefit a local community or earn commercial revenue ensuring that carbon credits are claimed to offset the airports' carbon footprint. The wind turbines could also be transferred between airports.

It is advisable that PEIA installation be trialled first and the CTIA installation thereafter, due to the flexibility of PEIA over CTIA in terms of unreserved space, fewer aircraft movements and thus fewer risks.

6. Proposed Operational Philosophy

(a) Technical

The wind farm installations at both Port Elizabeth and Cape Town airports will be an energy source installed within a mix of other energy sources. There will be at least one electricity source already installed when the wind farm installations are realized. The intention will be to install a smart grid to coordinate the energy sources for the purposes of continuous electricity supply according to the airport's demand and to ensure that the cost at which this comes is optimized. This smart grid will come in with the installation of the first alternative energy source that is incorporated for the airport's use.

Based on the nature of renewable energy being intermittent, the alternative energy source is meant to support a variable load energy requirement (as opposed to the base load energy requirements). Algorithms in the smart electrical grid

will coordinate the energy sources. The electrical output from the wind farm will feed into an energy storage/buffer medium to be drawn upon by the airport's energy demand at the required frequency.

The technical set-up in Figure 5 should be adopted based on the plant design and the success of the flywheel storage pilot being run in the next phase (FEL 3).

(b) Plant operation for business continuity and cost effectiveness

For the purposes of cost effectiveness, it is recommended that wind turbines with the greatest possible output capacity per unit be adopted to constitute the targeted total wind farm capacity, as this will decrease the number of moving parts and maintenance required as well as spatial demands.

A smart grid is essential to deliver the wind farm electrical output to the airport's electrical network in a cost-effective way. The smart grid principles should prioritize the renewable energy sources not containing battery storage as the energy generated needs to be used by the site as it is generated before other energy generation sources such as Eskom's grid power or fuel generators thus maximizing asset utilization on renewable energy sources not containing battery storage.

Wind power should not be considered or invested in as a primary energy source feeding airport base loads or critical loads, but rather as an augmentation or supplement to the main energy sources or to offset airport carbon emissions. Due to the uncertainty around wind turbines and radar communications interactions, wind farms total generation capacity should be limited to ensure that their existence does not interrupt airport operations.

(c) Operations and Maintenance activities

Operation of the wind farms and their integration into the airport electrical grids should be as per electronic algorithm via a smart grid. Operation anomalies and maintenance of the wind farms together with their related control systems will be contracted out as this is not a skill found within ACSA. Breakdown maintenance will be on a call-out basis. Preventative maintenance should be conducted as per the contract value to maintain operability and warranties. There should be a long-term plan in place that transfers skills in-house and develops local talent for operations and maintenance activities.

CONCLUSIONS

The harvesting of wind energy is feasible for Cape Town International Airport and Port Elizabeth International Airport but is not feasible for East London Airport and George Airport. Due to the uncertainty around wind turbines and airport radar operations working together, harvesting wind energy has been limited to serve the airports' varying load as opposed to serving the airports' base load. A 1kW Darrieus VAWT made by FT New Energy Company Ltd in China was used for the feasibility study at a height of an airport's typical street light, i.e. 10 metres. The height of the wind turbines is restricted and the location of the wind farm is critical in ensuring that radar communications are not interrupted or affected. Four eligible locations for CTIA and PEIA each have been selected by Air Traffic Navigational Services to narrow down the number of sites identified by ACSA for the wind farm installation.

As a next step to realizing wind energy in two of ACSA's airports, it is important that the four selected sites per airport be narrowed down further to preferably two for each airport based upon which ATNS can perform a computer simulation of the proposed wind farm to gauge the impact on radar and airport operations. Based on the outcomes of this computer simulation, the pilot phase of a mini-installation containing 10 1 kW VAWT should be installed (at PEIA and CTIA each) to monitor and confirm no impact on airport operations.

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